CERTIFICATE OF EXPRESS MAILING
"Express Mail" mailing label #: **EL872460860US**
Date of Deposit: **October 19, 2001**
I hereby certify that this paper or fee is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to: Box Patent Application; Assistant Commissioner for Patents; Washington, DC 20231.

Stephen S. Wentsler

MACHINING DEVICE AND METHODS

CROSS-REFERENCES TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 60/242,244 filed October 20, 2000, the entire disclosure which is herein incorporated by reference.

BACKGROUND OF THE INVENTION

Many devices are known for machining a workpiece. For example, it is well known to provide a rotating grinding wheel fabricated of an aluminum oxide abrasive material to machine the surface of a workpiece. For instance, U.S. Pat. No. 6,123,606 to Hill et al. discloses a conventional apparatus for grinding. As illustrated in FIG. 1 of Hill et al. a grinding wheel is provided with a jet of coolant that directly contacts the outer peripheral surface of the grinding wheel. The coolant is delivered as a high pressure jet that supplies fluid to the outer periphery of the grinding wheel prior to its rotation to the work zone. However, orienting the jet such that it directly contacts the

peripheral surface requires increased pressure and fluid velocity requirements which may result in cost increases for acquiring and operating the apparatus. .

Other attempts to provide lubrication have included injecting fluid along a rotational axis of the tool and into a central area of a porous material. As the tool rotates, the fluid is free to travel in various radial directions through the porous material to be discharged substantially equally at all locations of the periphery of the tool. Thus, the fluid is discharged from the tool in an uncontrolled manner resulting in significant portions of the fluid being discharged outside the machining zone. The uncontrolled discharging of fluid typically results in insufficient lubrication at the machining zone and loss of efficiency in the lubrication process.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to address and obviate problems and shortcomings of conventional machining devices and methods of machining.

It is a further object of the present invention to provide an improved performance machining device.

It is a further object of the present invention to reduce the fluid pressure required during the machining function.

It is still a further object of the present invention to reduct the cost and complexity of coolant nozzle assemblies.

To achieve the foregoing and other objects in accordance with the present invention machining devices are provided for machining a surface of a workpiece. One exemplary machining device includes a tool with a rotational axis and porous material with an outer peripheral surface disposed about the rotational axis and adapted to machine a surface of a workpiece. The machining device further includes a fluid delivery device oriented relative to the tool to disperse fluid to contact the tool primarily at a location inboard from the outer peripheral surface of the tool such that dispersed fluid is capable of flowing through the porous material. The machining devices provide a controlled radial discharge of fluid at a workpiece surface in use.

To achieve still further objects and in accordance with the present invention, methods of machining a workpiece are provided. On exemplary method includes the steps of providing a workpiece and providing a tool including a rotational axis and porous material with an outer peripheral surface disposed about the rotational axis. A fluid delivery device is provided and the exemplary method further includes the step of dispersing fluid from the fluid delivery device such that the fluid contacts the tool primarily at a contact location inboard from the outer peripheral surface of the tool. The tool is rotated about the rotational axis such that fluid flows through the porous material wherein the workpiece is machined with the outer peripheral surface of the tool at a machining zone wherein a controlled radial discharge of fluid is provided at the machining zone.

Still other advantages of the present invention will become apparent to those skilled in the art from the following description wherein there are shown and

described alternative exemplary embodiments of this invention. As will be realized, the invention is capable of other different, obvious aspects and embodiments, all without departing from the invention. Accordingly, the drawings and descriptions should be regarded as illustrative in nature and not as restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

While the specification concludes with claims particularly pointing out and distinctly claiming the present invention, it is believed the same will be better understood from the following description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a perspective view of portions of an exemplary machining device;

FIG. 2 is an elevational view of portions of the exemplary machining device of FIG. 1;

FIG. 3 is a sectional view along line 3-3 of FIG. 2;

FIG. 4 is a sectional view of another machining device in accordance with another exemplary embodiment of the present invention;

FIG. 5 is a sectional view of another machining device in accordance with yet another exemplary embodiment of the present invention;

FIG. 6 is a perspective view of portions of a machining device including at least one superabrasive working member;

FIG. 7 is a perspective view of portions of another machining device including at least one superabrasive working member;

FIG. 8 is a fragmentary view of portions of the outer member of FIG. 7 prior to the application of the adhesive layer or superabrasive working member;

FIG. 9 is a fragmentary view of portions of the outer member as illustrated in FIG. 8 after applying an adhesive layer over the hub peripheral surface;

FIG. 10 is a fragmentary view of portions of the outer member as illustrated in FIG. 9 after blowing fluid through the apertures to remove portions of the adhesive layer;

FIG. 11 is a fragmentary view of portions of the outer member as illustrated in FIG. 10 after application of at least one working member; and

FIG. 12 is a sectional view of portions of the tool along line 12-12 of FIG. 11.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

Referring now to the drawing figures in detail, where like numerals indicate the same elements throughout the views, FIG. 1 illustrates a perspective view of portions of a machining station 10 in accordance with one embodiment of the present

invention. The machining station 10 is designed to machine a surface of a workpiece and includes machining device 20 with a tool 30 and a fluid delivery device 70.

A wide variety of tools may be used in accordance with the present invention to machine a workpiece 90 to produce a machined surface 92 of the workpiece 90. For example, appropriate tools may be used to grind, shape, plane, mill, finish or otherwise machine a workpiece. It will be appreciated that exemplary tools may comprise a grinding wheel, a cutter, a wire brush wheel, or other tool designed to perform the desired machining function.

The exemplary embodiment depicted in FIG. 1 includes a tool 30 comprising a grinding wheel with a hub 34. An attachment member 80 is adapted to rotate the hub 34 about a rotational axis 32 during the machining process. To facilitate the machining function, the illustrated hub 34 includes an outer member 38 with an outer peripheral surface 44 including an abrasive material adapted to machine a surface of a workpiece 90. Unless otherwise indicated, abrasive material might comprise a material such as aluminum-oxide, silicon carbide, seeded gel ceramics, or the like. Furthermore, unless otherwise indicated, the abrasive material might comprise an open cell porous structure, or an at least partially open cell porous structure to facilitate passage of fluid through the abrasive material. In still further embodiments discussed below, the porous material might comprise a closed cell porous structure. Moreover, structures other than porous structures could be provided depending on the tool being used, for example, the spaces between the bristles of a wire brush wheel.

The exemplary hub 34 can further include a support member 36 structured to transmit torque from the attachment member 80 to the outer member 38. The support members of the exemplary embodiments of the present invention may comprise various structures designed to transmit torque and support the outer member while saving material, reducing the mass of the tool and/or reducing manufacturing costs. For example, the exemplary embodiments in accordance with the present invention might include a support member comprising a disk (e.g., see 36 in FIGS. 1-2). Although not shown, support members can include a disk with openings therein or may simply include a plurality of spokes to save material and reduce the mass of the tool while maintaining the structural integrity of the hub. It is also understood that the support members in accordance with the present invention can comprise a different material attached to or integral with the outer member. For example, a relatively inexpensive aluminum disk might be used as the support member with the outer member comprising abrasive material attached to the outer perimeter of the aluminum disk. Support members could also comprise other metals (e.g., steel), another grinding wheel support structure, or other member with the required mechanical properties. The embodiments of the present invention, as illustrated in the exemplary embodiment of FIGS. 1 and 2, form the outer member 38 and support member 36 as a single monolithic piece from an abrasive material to simplify the manufacturing process.

FIGS. 1 and 2, as well as the other embodiments of the present invention, may include a cavity defined by surfaces of the outer member and the support member.

Such a cavity may be designed to receive fluid during a machining operation. For example, as shown in FIGS. 1-3, as well as the other embodiments of a tool with a cavity, an outlet 72 of the fluid delivery device 70 may be at least partially located in the cavity 46 of the tool 30 to disperse fluid to contact the tool primarily at a contact location 74 that is inboard from the outer peripheral surface 44 of the tool 30. Locating the outlet 72 within the cavity 46 may be desirable to place the outlet 72 immediately adjacent the contact location and to direct the fluid stream approximately normal to the cavity surface 48 at the contact location 74. Locating the outlet 72 within the cavity 46 such that it is immediately adjacent the contact location may be desirable to reduce the required fluid velocity and fluid pressure while effectively penetrating the porous material.

With reference to FIGS. 1-3, as well as the additional embodiments of the present invention with a cavity defined in the tool, the outlet may alternatively be located outside the cavity and oriented to direct fluid to the contact location. For example, the outlet may be located inboard from the outer peripheral surface of the tool without actually being located in a cavity portion. In still further embodiments, the outlet could be located outboard from the outer peripheral surface while being oriented to primarily direct fluid to the contact location. Locating the outlet outside the cavity, if provided, might be desirable for clearance issues and may prevent interference between the outlet and the tool or portions of the machining device for example.

As best illustrated in FIG. 2, as well as any of the embodiments of the present invention, the tool 30 and the fluid delivery device 70 can be positioned relative to one another such that contact location 74 can also be located in advance of a machining zone 95. Arranging the tool 30 and fluid delivery device 70 such that the contact location 74 is in advance of the machining zone 95 allows a controlled radial discharge of fluid wherein portions of the fluid dispersed from the fluid delivery device 70 may pass through the outer member 38 to exit the outer peripheral surface 44 substantially adjacent the machining zone 95.

In each of the exemplary embodiments of the present invention, the tool can comprise a portion adjacent the peripheral surface adapted to inhibit fluid flow to assist in controlling radial discharge of the fluid to the peripheral surface at the machining zone 95. For example, the lateral surface, adjacent the peripheral surface, may comprise a coating, such as fluid resistant paint, rubber, or other material to inhibit or prevent fluid flow. In other examples, a surface may comprise a plate of fluid impermeable material. As illustrated in FIGS. 1-3, for instance, a surface of the outer member 38 may comprise a coating of paint 50 adapted to inhibit lateral fluid flow through the outer member 38. As shown in FIG. 3, the material 50 could be provided on each lateral surface of the hub 34.

The fluid delivery devices of the exemplary embodiments used in accordance with the present invention may comprise a variety of fluid dispersion systems designed to dispense fluid. The fluid could be selected to provide lubrication, cooling, and/or removal of residual machined material during the machining

operation. Exemplary fluids that might be used include, but are not limited, to the following: oil (e.g., water soluble oil), water soluble synthetic material (e.g., water soluble synthetic hydrocarbons), semi-synthetic material (e.g., water soluble semi-synthetic hydrocarbons). In one example, a solution could contain about 5% to about 20% water soluble oil. In one particular example, a solution could comprise about 7% to about 10% water soluble oil.

The fluid delivery devices of the present invention can also be designed to pressurize the fluid for release at an adequate velocity to facilitate penetration of the fluid in porous material of the tool. A larger pressure (e.g., 1000 psi) and a high fluid velocity may be required when a large gap exists between the outlet and the contact location. In applications where the outlet is located immediately adjacent the contact location (e.g., 0.01 inches), a lower fluid pressure (e.g., 200 psi) and fluid velocity may be sufficient to penetrate the porous material. For example, as illustrated in FIG. 1, locating the outlet 72 within the cavity 46 permits the outlet to be located adjacent the contact location 74, therefore reducing the pressure requirements of the fluid delivery device 70. The pressure requirements may also be dependent on the porosity and the open cell structure of the tool material. An increase in the porosity and open cell structure will enhance fluid flow, thereby reducing the pressure requirements of the fluid delivery devices. In addition, the heat and chip generation of the tool during the machining process will further determine the pressure requirements for effective fluid delivery devices. A lower fluid pressure and fluid velocity requirement may be introduced with lower chip and heat generation applications while additional fluid

pressure and velocity may be necessitated for more demanding applications including a larger amount of chip and/or heat generation.

The exact position of the contact location of the various embodiments of the present invention can be selected to facilitate a controlled radial discharge of fluid to the machining zone. The exact position, for example, may depend on the rotational speed of the tool as well as the material characteristics of the tool (e.g., porosity size, porosity density, open cell structure of the pores, thickness of the material, etc.). For example, as illustrated in FIG. 2, the contact location 74, is located at an angle “a” in advance of the outermost portion 94 of the machining zone 95. As illustrated in FIG. 2, the angle “a” may range from about 0° to about 90°, for example from about 30° to about 60°. However it is understood that the angle “a” could also range from about 0° to about 180° or even about 0° to about 360°. It might be an advantage to minimize the angle “a” to reduce fluid being distributed away from the machining zone 95.

In order to compensate for changes in the material characteristics of the tool, the fluid delivery device of each of the embodiments of the present invention could be adapted to modify the contact location, fluid pressure, fluid velocity and/or other parameters to assist in maintaining proper dispersal of fluid at the machining zone. For example, the contact location of each of the various embodiments of the present invention can also change during the machining process. For example, as the outer member 38 wears away from use, the angle “a” may be reduced to compensate for the reduced thickness of the outer member 38. Alternatively, or in addition, the fluid

velocity and/or fluid pressure may be reduced as the thickness of the outer member decreases.

In exemplary embodiments, fluid delivery device parameters can be modified during the machining process. For instance, the parameters could be modified based on a programmed theoretical attrition rate of the abrasive material without feedback from the machining station. In other examples, the machining station can be designed to provide feedback to the fluid delivery device to assist in maintaining proper dispersal of fluid at the machining zone. For example, FIG. 1 depicts a conducting element 13, such as an electrical wire, to provide feedback of gauged changes in torque applied by a spindle 14 of a machining center 12 during the machining process. Increases in torque would occur as the abrasive material wears away since the fluid dispersion at the machining zone would not be optimized. Thus, in response to an increase in torque requirements, the angle "a", fluid velocity and/or pressure could be reduced to optimize dispersion of fluid to the machining zone. While FIG. 1 illustrates an electrical wire 13 to provide feedback, other feedback devices could also be used (e.g., wireless transmission, etc.).

A machining center 12 may be used to operate the tool of the machining devices of the present invention. For example, the machining center 12 may be of the type generally known as a computer numerically controlled ("CNC") machine which permits various tool manipulations along a plurality of rotational and linear axis, for machining, such as grinding, milling, planing, cutting, honing, boring, polishing or other machining operations wherein at least a portion of the material from a

workpiece is removed. A CNC machine can permit a wide range and potentially unlimited tool orientation with respect to the workpiece for performing various machining operations.

In use, the spindle 14 of the machining center 12 may receive and secure the attachment member 80 wherein rotation of the spindle 14 will result in a corresponding rotation of the tool 30. A workpiece 90 to be machined (e.g., by grinding, milling, planing, cutting, honing, boring, polishing or other machining operation) is also secured to a work table 98 with a work holder 99.

The fluid delivery device 70 is then oriented relative to the tool 30 to disperse fluid to contact the tool primarily at a location 74 inboard from the outer peripheral surface 44. Fluid is pressurized and thereafter dispersed through the outlet 72 in a dispersion direction 76 such that the fluid contacts the tool 30 primarily at the contact location 74 inboard from the outer peripheral surface 44 of the tool 30. The velocity of the fluid can provide sufficient momentum to assist in penetrating fluid into the porous material of the tool 30.

The tool 30 also rotates about the rotational axis 32 such the centrifugal force acting on the fluid further facilitates movement of portions of the dispersed fluid through the outer porous member 38 to thereby exit within the machining zone range defined within angle "b" advance of the outermost portion 94 of the machining zone 95. Dispersing the fluid within the machining zone range may facilitate cooling of the tool and/or workpiece, lubrication to reduce heat generation, and/or chip removal.

Residual fluid may thereafter be recovered by a container or sump 96. The fluid delivery device 70 can include an apparatus 71 designed to draw fluid from the lower portions of the container 96 with the use of a conduit 75. The apparatus 71 might include a pump and filter assembly to process and pressurize the fluid prior to distributing the fluid through the conduit 73 to be dispersed through the outlet 72. While not shown, the conduit may be self supported or be provided with a support structure to adjust and maintain the outlet 72 in proper position.

FIG. 4 depicts an alternative embodiment of the present invention including a machining device 120 with a rotational grinding tool 130 and fluid delivery device 170. The machining device 120 is designed to be connected to a spindle in fluid communication with a fluid source. For example, U.S. Pat. No. 5,775,853 that issued July 7, 1998, the entire disclosure which is herein incorporated by reference, discloses a machining center and spindle that can be used with the concepts of the present invention. In particular, the fluid delivery device 170 includes an attachment member 180 adapted for fluid connection with the spindle of the machining center. The attachment member 180 is connected to a hub 134 including an abrasive material, such as the material associated with the hub 34 described in relation to FIGS. 1-3 above. In one exemplary embodiment, the attachment member 180 is connected to a support member 136 of the hub 134 while the outer member 138 is attached to the support member 136. The outer member 138 includes a outer peripheral surface 144 adapted to machine a surface of a workpiece.

A deflection member 178, such as a circular plate, may be attached to the support member 136 for rotation therewith. The deflection member 178 may be mounted within a cavity 146 with an attachment mechanism, such as stand-off legs 177. It will be understood that the deflection member could be designed for adjustment within the cavity in order to adjust the fluid dispersion stream and/or to accommodate attrition of the abrasive material of the outer member 138 by retracting the deflection member 178 deeper into the cavity 146. The deflection member 178 assists in directing fluid passing through the attachment member 180 in a dispersion direction 176 to the contact location 174 on the interior surface 148 of the cavity 146. As illustrated in FIG. 4, the fluid is dispersed radially from a circular outlet 172. The dispersed fluid fans out to contact portions of the tool at a circular contact location 174. As with the other embodiments of the present invention, the velocity of the fluid facilitates penetration of the porous material after the fluid encounters the contact location.

As the tool 130 rotates about the rotational axis 132, centrifugal forces further encourage fluid to travel along the interior surface 148 and/or through the tool material (e.g., an open cell porous material) to be distributed adjacent the outer peripheral surface 144. To assist in controlling the radial discharge of the fluid at the workpiece surface, the outer surface of the hub 134 may include portions 150a, 150b that inhibit fluid flow. The portions 150a, 150b might comprise a coating of fluid resistant paint or other arrangement as described in relation to the portions 50 described above with reference to FIGS. 1-3. Moreover, 150b or the entire support

member 136 could comprise a plate of material (e.g., a substantially non-porous aluminum plate) that would be effective to deter fluid flow. In this embodiment, it might still be desirable to provide portion 150a as a coating of fluid resistant paint or the like to prevent interference with the workpiece as it is being machined and as the porous material adjacent the peripheral surface 144 begins to be worn away during the machining process.

FIG. 5 illustrates yet another embodiment of a machining device 220 including a tool 230 and a fluid delivery device 270. The fluid delivery device 270 is oriented relative to the tool 230 to disperse fluid to contact the tool 230 primarily at a location 274a, 274b inboard from the outer peripheral surface 244 and on respective sides 252, 254 of the tool 230. In one embodiment, the outlets 272a, 272b are located immediately adjacent the corresponding contact locations 274a, 274b to minimize the required fluid pressure necessary from the fluid delivery device 270. As with the embodiment of FIGS. 1-3, however, it will be understood that one or both of the outlets 272a, 272b could be located outboard of the outer peripheral surface 244. In such an embodiment, an additional device (e.g., deflection members, etc.) might optionally be provided to assist in directing fluid to the contact location.

As illustrated, the fluid delivery device 270 could comprise two opposed outlets 272a, 272b, adapted to direct fluid in a fluid stream direction 276a, 276b towards one another. In one embodiment, the outlets 272a, 272b are oriented relative to one another to provide parallel fluid streams and can be parallel to the rotational axis 232. In still another embodiment, the outlets 272a, 272b may be coaxial to direct

fluid along the same path in opposite directions. In still further embodiments, although not shown, the fluid stream directions 276a, 276b may be directed at an angle relative to one another. For example, one or more of the fluid streams might be directed toward the tool and downwardly toward the workpiece.

While the embodiment of FIG. 5 illustrates the fluid delivery device 270 including two outlets 272a, 272b, other embodiments of the fluid delivery device 270 could comprise a single outlet or three or more outlets in accordance with the present invention.

In use, fluid travels from the outlets, 272a, 272b in corresponding directions 276a, 276b to contact location 274a, 274b and therefore penetrating into the porous material of the grinding wheel 230. As with the previous embodiments, the wheel may be rotated with an attachment member 280 that is attached to a machining center. The wheel 230 then rotates about the rotational axis 232 wherein centrifugal forces encourage fluid to travel through the porous material to be distributed adjacent the outer peripheral surface 244 at the machining zone. As with the exemplary embodiments described throughout this application, one or more of the contact locations may be preselected, or the fluid delivery parameters could otherwise be modified to assist in providing a controlled radial discharge of fluid at a workpiece surface in use.

FIGS. 6-12 illustrate two alternative embodiments for providing a grinding wheel with a superabrasive material for alternative machining applications.

Exemplary superabrasive materials may include Cubic Boron Nitride (CBN), diamond, polycrystalline products or other superabrasive material.

FIG. 6 depicts portions of a machining device 320 including a tool 330 and fluid delivery device 370 that may be a modification of a tool similar to the tool 30 described in relation to the embodiment of FIGS. 1-3 above. In fact, in one exemplary embodiment, the tool 30 described above can be retrofitted to provide the tool 330. It might be beneficial, for instance, to retrofit a tool 30, such as a porous abrasive grinding wheel, to provide a tool 330 with a superabrasive material. In still further embodiments, a porous abrasive grinding wheel or other tool may be retrofitted or upgraded toward the end of its useful life to a tool 330 with a superabrasive material.

An exemplary tool 330 includes a hub 334 with a support member 336 and outer member 338. One or more working members 356 are attached to the hub peripheral surface 340, for example, with a fastener, adhesive or the like. In still further embodiments an adhesive could be applied in a matrix, random, or discontinuous pattern to produce interstitial voids for fluid flow between the outer member 338 and the working member 356. For example, the adhesive could be applied as a matrix similar to that shown in FIGS. 9-11. Alternatively, or in addition, the adhesive could be applied as a plurality of droplets or otherwise applied to provide alternative adhesive and void portions. In still further embodiments, a fluid permeable adhesive might be used. A portion 350 that inhibits fluid flow, such as a coating of material, may also be applied to lateral surfaces, such as the opposed lateral

surfaces, of the outer member 338, the support member 336, and/or the working member 356 adjacent the outer peripheral surface 344 of the tool 330 to direct fluid flow to the peripheral surface 344 and thereby assist in controlling the radial discharge of the fluid at the workpiece surface.

In one example, as illustrated in FIG. 6, a plurality of working members 356, such as superabrasive tiles, could be attached to the hub peripheral surface 340 such that the working members 356 substantially abut one another. In this embodiment, the open cell nature of the superabrasive is designed to facilitate substantial fluid diffusion through the working members 356. In addition, or in other embodiments, the working members 356 could comprise open or closed cell pores wherein the tiled working members are spaced apart from one another to allow fluid leakage between adjacent working members 356.

In use, the fluid delivery device 370 directs fluid in a dispersion direction 376 to the contact location 374 located inboard of the peripheral surface 344. As illustrated, the contact location 374 could be located on an interior surface 348 of a cavity 346 of the tool. Moreover, the contact location may be preselected, or fluid delivery parameters could otherwise be modified to assist in providing a controlled radial discharge of fluid at a workpiece surface in use. In the illustrated exemplary embodiment, the outlet 372 can be located within the cavity 346 of the tool 330. The velocity of the fluid permits penetration into the outer member 338 by entering the porous structure of the outer member 338. Centrifugal forces then act on the fluid to further encourage the fluid to travel through the outer member 338, the interstitial

spaces between the adhesive, if provided, to the outer peripheral surface 344 adjacent the machining zone. An open cell superabrasive working member 356 could be provided to facilitate diffusion of the fluid through the working member 356 to the peripheral surface 344. Using an open cell superabrasive working member 356 would permit locating the working members 356 close to one another, perhaps in abutment, therefore increasing the abrasive surface area in contact with the workpiece to enhance the machining efficiency and quality. In another example, either an open cell or a closed cell superabrasive working member 356 could be used wherein the working members 356 are spaced from one another to permit fluid leakage between adjacent working members 356 to the peripheral surface 344. Spacing the working members 356 reduces the total amount of superabrasive material necessary to initially produce the tool 330 while permitting substitution of the open cell superabrasive with a less-expensive closed cell superabrasive.

FIGS. 7-12 depict another embodiment of a machining device 420 with a tool 430 and fluid delivery device 470. The tool 430 includes at least one working member 456 that may be structured and positioned in the manner described in relation to the working member(s) 356 described above. The tool 430 includes a hub 434 with an outer member 438 supported by a support member 436. The hub 434 may comprise a material at least partially impermeable to fluid. For example, the hub 434 could comprise substantially solid metal, substantially closed cell porous material, or other material having a sufficient strength to support the working member(s) 456. The outer member 438 includes a plurality of apertures 442 that might be arranged

randomly or in a pattern. For example, as illustrated in FIG. 8, the apertures 442 could be arranged in offset rows. The number, size, shape and specific location of the apertures, as illustrated in FIGS. 7-12, are one exemplary aperture arrangement. In other embodiments, a significantly greater number of apertures, of smaller size for example, could be provided to more evenly distribute the fluid to the outer peripheral surface 444 of the tool 430.

FIGS. 8-11 illustrate one method of making a tool 430. A hub 434 is provided with an outer member 438 including a plurality of apertures 442. An adhesive layer 458 is applied to the hub peripheral surface 440. As illustrated in FIG. 9, the adhesive layer 458 could be applied in a matrix, random, or discontinuous pattern to provide interstitial voids 460 that facilitate fluid communication between the apertures 442 and the working members 456. To further remove unwanted portions of the adhesive overlaying the apertures, a fluid (e.g., air) could be blown outwardly from the interior surface 448 of a cavity 446 through the apertures 442 to blow away portions of the adhesive layer overlaying the apertures 442, as shown in FIG. 10. It will also be appreciated that a structural plunger or other probe can also be used to remove the adhesive layer overlaying the apertures 442. The step of blowing through the apertures, however, may not be necessary when the adhesive is applied with interstitial voids or wherein a fluid permeable adhesive is applied. In still another example, the adhesive layer could be applied as a continuous layer wherein fluid is blown through the apertures 442 to remove unwanted portions of the adhesive layer

overlaying the apertures 442. As shown in FIG. 11, the working members 456 can then be applied over the adhesive layer 458.

FIG. 12 illustrates a sectional view of the tool 430 wherein the interstitial void 460 is in fluid communication with the aperture 442 formed in the outer member 438. As further illustrated in FIG. 12, a portion 450, such as a coating of material, that inhibits fluid flow may also be applied to the lateral surfaces of the working members 456 adjacent the outer peripheral surface 444 to direct fluid to the peripheral surface 444 and thereby assist in controlling the radial discharge of the fluid at the workpiece surface.

In use, the workpiece 90 is clamped with a work holder 99 to a work table 98. The tool 430 is provided adjacent the surface of the workpiece to be machined. The tool 430 is rotated about its rotational axis such that the outer peripheral surface 444 may contact the workpiece at a machining zone. Fluid is dispersed from the outlet 472 of the fluid delivery device 470 in a dispersion direction 476 to assist in cooling, lubrication and/or chip removal. The fluid is dispersed from the delivery device to contact the tool 430 primarily at a contact location 474 inboard from the outer peripheral surface 444 of the tool 430. As depicted in FIG. 7, the contact location 474 may be located on the interior surface 448 of the cavity 446 and may be preselected, or other fluid parameters could otherwise be modified, to assist in providing a controlled radial discharge of fluid at a workpiece surface in use. The velocity of the fluid exiting the fluid delivery device 470 causes the fluid to enter the aperture 442 to eventually diffuse in the working members 456. Centrifugal force, due to rotation of

the tool 430, further causes outward movement of the liquid through the apertures 442 and/or through the working members 456 to the outer peripheral surface 444 at the machining zone. In one example, the apertures 442 are in fluid communication with the interstitial voids 460 defined in the adhesive layer 458 to permit fluid communication with the working members 456. The fluid may then travel through the porous cell structure (e.g., open cell structure) of the working members 456 and/or leak through the spaces between the working members 456 to be introduced at the machining zone.

The foregoing description of the various embodiments of the invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many alternatives, modifications and variations will be apparent to those skilled in the art of the above teaching. Accordingly, this invention is intended to embrace all alternatives, modifications and variations that have been discussed herein, and others that fall within the spirit and broad scope of the claims.